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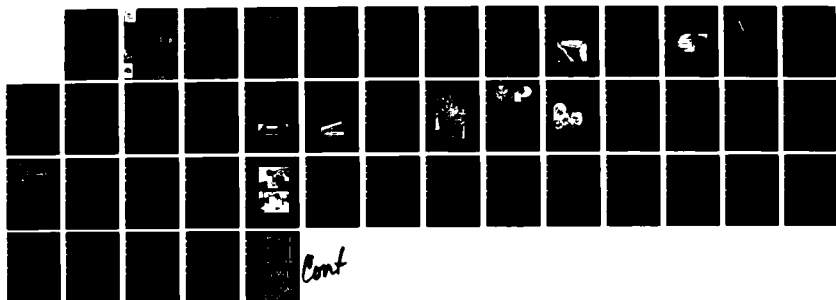
EPOXY-RESIN GROUTING OF CRACKS IN CONCRETE(U) ARMY  
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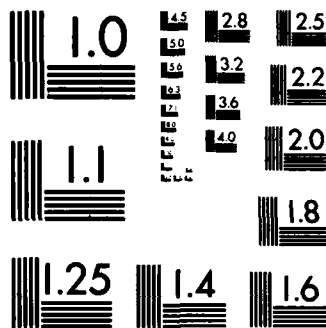
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# EPOXY-RESIN GROUTING OF CRACKS IN CONCRETE

by

Dennis L. Bean

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DEPARTMENT OF THE ARMY  
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## PREFACE

The investigation described in this report was conducted during the period June 1983 to December 1984 by members of the staff of the Concrete Technology Division (CTD) of the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES). The research for this report was authorized under Military Research and Development Program AT40 CO-009, Project No. 6.27.19A 4A162719AT40.

The investigation was performed under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. John M. Scanlon, Chief, CTD, and under the direct supervision of Mr. Richard L. Stowe, Chief, Materials and Concrete Analysis Group. This report was prepared by Mr. Dennis L. Bean, SL, and edited by Ms. Janean Shirley, Publications and Graphic Arts Division.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)  
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons	3.785412	litres
inches	2.54	centimetres
ounces (US fluid)	0.02957353	cubic decimetres
pints (US liquid)	0.4731765	cubic decimetres
pounds (force) per square inch	47.88026	pascals

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\* To obtain Celsius (°C) temperature readings from Fahrenheit (°F) readings, use the following formula:  $C = (5/9)(F - 32)$ . To obtain Kelvin (K) readings, use:  $(K) = (5/9)(F - 32) + 273.15$ .

## EPOXY-RESIN GROUTING OF CRACKS IN CONCRETE

### PART I: INTRODUCTION

1. It is possible to restore the original tensile or shear strength to a cracked concrete structural element by the injection of an adhesive material into the cracked concrete. Low-viscosity epoxy resin specifically developed for repairing cracks has proven to be the most successful method (Chung 1981; Hewlett and Morgan 1982; Kuenning 1973; Lee, Wright, and Hanson 1971; Popov and Bertero 1975), provided the bonding surface of the concrete at the crack interface is clean and sound and that the crack is not a working crack. The process of injecting a material into a void is called grouting.

2. The preferred method of grouting cracks is epoxy-resin injection with entry ports (Figure 1). The objective is to have as few injection points as possible, to achieve maximum resin penetration at a low operating pressure. As a general rule, the injection hole spacings should be equal to or slightly wider than the depth of the concrete to be injected.



Figure 1. Injection ports bonded into drilled holes in cracks

## PART II: PREPARATION FOR GROUTING CRACKS

### Conditions

3. Cracks in concrete may vary from very small to very large. Very small cracks cannot be grouted because the epoxy resin cannot penetrate them. Injection of large cracks is not practical because of creep and thermal expansion problems with the epoxy. A general range of crack widths to be injected is 0.002 to 0.25 in.\* with special consideration to be given to the width of the crack. The crack should be free of dust, oil, or any debris that might block the flow of the epoxy. Dust and oil will prevent the epoxy from bonding to sound concrete; they will act like bond breakers. When the concrete is cool, the cracks will be wider, allowing deeper penetration of the grout into the smaller cracks.

4. Whichever epoxy system is selected, consideration must be given to the amount of time required for the epoxy to bond so that the structure can be placed back into service. Any epoxy that requires over 14 days to achieve its maximum bond strength (for any size crack) should not be used unless previously authorized. The epoxy should also have a minimum bond strength, tested in accordance with ASTM D 882-78 (American Society for Testing and Materials 1983). A value of 1,400 psi is considered acceptable (Kuenning 1973). Desirable qualities of epoxy resins are listed in Appendix A. Appendix B is a list of epoxy resin manufacturers.

### Moving or Working Crack

5. Working cracks require special consideration. They continuously move (opening and closing), like expansion or contraction joints. This type of crack occurs in a section where the tensile stresses are greater than the tensile strength of the concrete (due to poor design or unexpected loading). If this type of crack is grouted and the stresses are still present, the concrete will crack again in the same region. These cracks extend the entire depth and length of the concrete, usually in a fairly straight line. This

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\* A table of factors for converting non-SI units of measurement to SI (metric) units is given on page 4.

report suggests that working cracks not be grouted until the excessive stresses are eliminated or reduced significantly. This type of crack should be routed and sealed to prevent the entry of water and debris.

6. If a crack has resulted in one or two sections that can be secured in place, it may be repaired as a full-depth crack. However, if the cracking has produced fragmentation, complete removal of the concrete may be the best method of repair.

7. The injection ports can be bonded into the drilled holes with a commercially available fast-setting epoxy resin. After the ports have been properly installed, the cracks are sealed in order to confine the injected grout until initial set is achieved (Figure 2). Any sealing material may be used, provided it confines the injected epoxy in the crack when the injecting pressure is applied.



Figure 2. Cracks and injection ports being sealed

#### Guidelines for Injection Port Installation

8. Holes are drilled directly into the crack or drilled to intercept the crack, for the purpose of attaching injection ports. The ports can be any material that will allow the epoxy to be forced into the cracks. They can be pipe nipples, tire valves, or manufactured epoxy injection ports (Figure 3).

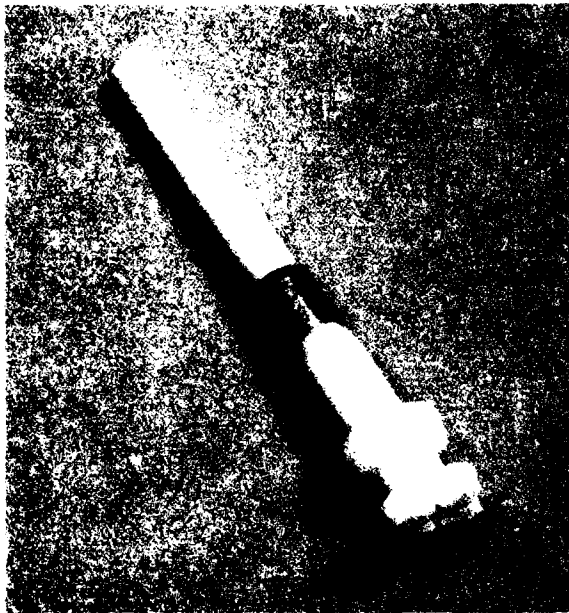


Figure 3. Manufactured injection port

the cracks are more than 2 ft in depth, full penetration may be difficult to achieve because of equipment limitations. Intermediate ports should be established to monitor the flow of epoxy (Figure 4).

Guidelines for Port Spacing in Cracks Extending the Full Depth of the Member

10. For members 1 ft or less in thickness, ports should be placed in the crack on one side only and spaced at the thickness of the members.

11. For members greater than 1 ft and less than 2 ft in thickness, ports should be placed at the intersection of the crack with all available sides and spaced no more than the thickness of the member.

Copper tubing, 1/4 in. in size, with a flared end works very well. Ports must be checked before they are permanently installed to be sure that the grouting equipment's injection nozzle will properly connect to them. Grease fittings can be used as an alternate or backup system. In these cases, a grease gun is required to supply the injecting force.

Some Guidelines for Port Spacing

9. If cracks are less than 0.005 in. wide, entry ports should be spaced not more than 6 in. apart. If

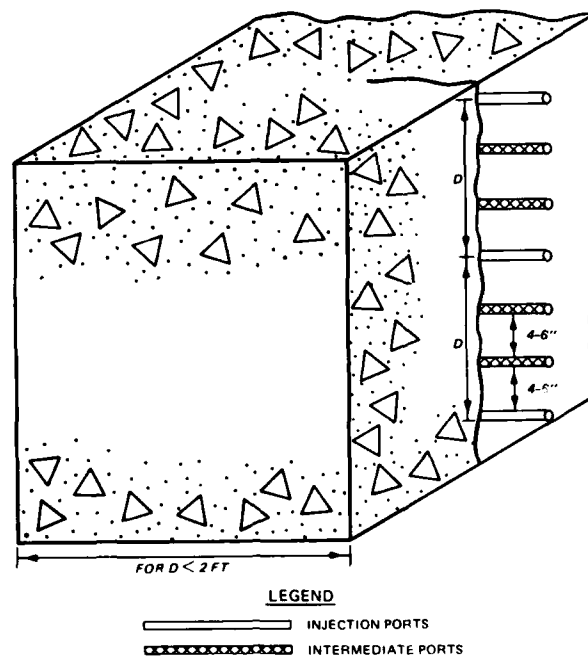


Figure 4. Injection and intermediate ports

12. For members greater than 2 ft in thickness, ports should be placed at the intersection of the crack with all available sides and spaced according to the guidelines set forth for partial-depth cracks. The first and last entry ports should be established at or near the bottom and top, respectively, of any vertical crack, or at the ends of any horizontal crack in a vertical or horizontal member.

#### Sealing Cracks

13. The preferred sealing material is a thixotropic epoxy, which can be obtained from most epoxy-resin distributors. The injecting epoxy can be modified to a thicker consistency by the addition of a filler material, so that it can be used as a sealant. The manufacturer can give the correct amount of filler to be added to make a good sealant. After the sealant has set, it should have the capability to contain the grout at an injecting pressure of about 100 psi and should be able to maintain the pressure for up to 10 minutes. The Kansas State Department of Transportation uses silicone caulking compound to seal cracks that are to be grouted with an epoxy resin (Stratton and Crumpton 1984).

#### Cleaning the Interior of the Crack

14. After the ports have been placed and the sealant is strong enough to permit grouting, the crack is flushed with high-pressure water to remove any internal contamination which may inhibit the bonding of the faces of the crack and also to check for leakage around the sealant. To ensure a better bond, the concrete should be free of water. The residual water in the cracks can be blown out with clean, dry, compressed air. Although there may not be sufficient time to allow the concrete to dry completely, standing water in the cracks should be avoided.

## PART III: MATERIALS

### General Properties of Epoxy Resin-Hardener Compounds

15. A thermosetting plastic is a plastic which, when cured by application of heat or by chemical means, changes into a substantially infusible and insoluble product (American Society for Testing and Materials 1984e). The compound is formed from an epoxy resin and a hardening agent (sometimes referred to as the catalyst) with enough heat (usually temperatures greater than 50° F) to complete the cross-linking of the two materials. Although heat is required to start the reaction, the reaction is exothermic. This sometimes can limit the applications of the product, if excessive heat is generated. The process of going from an epoxy resin-hardener liquid mixture to an epoxy resin-hardener solid is referred to as curing or setting. All epoxy resin-hardener reactions are temperature sensitive; therefore, environmental conditions are important. Since the epoxy compound is a thermosetting material, close control of temperature must be exercised before and during mixing, and after application to ensure that heat will be sufficient to permit the epoxy mixture to cure in a given time. At normal ambient temperatures, it is possible for a mixture of epoxy resin and hardener to go from a liquid to a solid state in a matter of several minutes. Epoxies that cure below 50° F are specially formulated and cannot be used at the higher temperatures because the pot life of the mixture will be too short. Pot life is the length of time after mixing for which a given quantity of epoxy resin and hardener can remain in a given container before it begins to gel. The epoxy will begin to thicken and harden before it can fill the entire crack. Once cured, the epoxy compound will not melt; however, most systems become more elastic at higher temperatures. Most systems will remain functional up to about 150° F.

16. Epoxy compounds are generally formulated in two components. Part A is the portion containing the epoxy resin and Part B is its hardener (American Concrete Institute 1980). The properties of the epoxy system should be tailored to meet the specific needs for each type of application; thus it is unlikely that a system consisting only of an epoxy resin and a pure hardening agent will find wide use. It is for this reason that the epoxy resin systems sold commercially are generally the products of formulators who specialize in modifying the system with flexibilizers, extenders, diluents, and fillers to

meet specific end-use requirements, or reduce cost. Any epoxy used with concrete must meet ASTM C 881-78 (American Society for Testing and Materials 1984d) and be used in accordance with ACI Committee 503 recommendations (American Concrete Institute 1980).

#### Description of System to be Used

17. Since it is practically impossible to find an epoxy resin and hardener system that is ideal in every respect for each particular application, a system must be selected to meet the requirements of the job (e.g., temperature, width of the crack, etc.). Narrow cracks (0.002 to 0.050 in.) require a low-viscosity epoxy with a more rapid gel time. The wider cracks can accommodate an epoxy with a higher viscosity but require a longer gel time to avoid excessive heat generation. The system must be 100 percent reactive (no non-reactive solvent) and must be moisture insensitive if the concrete is wet or damp or if water is used to flush out the crack. Epoxies that are formulated for the purpose of adhering to damp concrete are commonly referred to as moisture-insensitive epoxies.

18. Systems can be capable of grouting cracks up to 1/4 in. in width; however, good judgment must be exercised in these cases. More heat will be generated by the epoxy in these larger cracks because more epoxy is there to react. Too much heat can cause excessive expansion, resulting in cracking as the epoxy returns to ambient temperature. When an epoxy is to be used for underwater crack injection, filler material must be added to obtain a higher density material. This denser epoxy, when properly injected, will displace water in the crack and after curing will bind both faces of the crack to form a seal, thus restoring the continuity of the concrete member.

#### Curing

19. Curing of the epoxy mixture is dependent on both temperature and time. The higher the temperature, the faster the cure. High temperature combined with large masses of epoxy can cause excessive temperature, resulting in a very short pot life for the mixture.

20. When concrete and ambient temperatures exceed 90° F, difficulties may be experienced in application of the epoxy mixture due to acceleration of



the reaction, which affects the hardening rates. If ambient temperatures over 90° F are anticipated, work should be scheduled when the temperature is lower, such as in the early morning hours.

21. To check the curing in inaccessible locations it has been found useful to apply a thin coat of the bonding epoxy mixture on a nearby concrete surface and to ensure that it hardens after a given length of time.

#### Temperature Effects

22. The rate of curing and the viscosity of the epoxy mixture are affected by temperature; therefore, the ease and effectiveness of epoxy grouting are greatly influenced by the temperature of the concrete in which the epoxy mixture is injected.

23. As the temperature decreases, the epoxy mixture becomes thicker, making grouting more difficult. Heating of the mixed compound before injecting will improve its penetrability. But once it enters a narrow crack, it will almost immediately lose its heat to the surrounding concrete, therefore flowing less easily.

24. When the concrete and ambient temperatures are lower than 40° F, the temperature of the concrete should be elevated to ensure effective and adequate curing of the epoxy mixture in a reasonable length of time. To accomplish this elevation in temperature, an inclosure should be made to cover the concrete to be repaired. This would allow the concrete to be heated fairly uniformly by using either circulating warm air or radiant heaters. Localized heating should be avoided. The heat should be applied in a manner that will maintain surface temperatures below 90° F during the curing period. Direct flame heating of the concrete surfaces should be prohibited as it is hard to control the temperature.

25. Since the interior of the concrete will stay cold much longer than the surface, even if heat is applied, ice crystals may be present within the crack. None of the epoxy systems will bond to ice. If ice is present in the crack, it will disrupt the bonding of the epoxy and the concrete, leaving voids when the temperature rises enough to melt the ice. Precautions should be taken to ensure that the interior of the concrete is warm enough to melt any ice that might be present and also warm enough to start the cross-linking reaction. As the temperature rises and longer pot lives are desired, pot life

can be extended by shading the material and equipment from direct sunlight. If a still longer pot life is needed, the material can be cooled in a refrigerator or ice bath.

### Mixing

26. Since the basic chemistry requires every particle of hardener to connect and join with its epoxy-resin counterpart, special attention must be directed to mixing. Complete mixing to a uniform resin-hardener mixture is essential. Insufficient mixing of the resin-hardener mixture will result in weak spots in the hardened compound. If the epoxy resin and the hardener are of different colors, streaking in the mixed components will be noticed if mixing is not complete. The epoxy resin and hardener should be completely mixed before the addition of any filler or aggregate.

27. Mixing of the co-reactants can be done by any method that assures complete mixing. It can be accomplished by hand mixing, paddle mixing with a drill motor, or by using a mortar mixer. Whichever method is used, mixing should continue until the compound is homogeneous. The entire unit should be mixed - an attempt should not be made to proportion the components of the unit. Components should not be used if the cans have been opened longer than a week. Generally, a unit is one container of component 'A' and one container of component 'B'.

28. In field work where low ambient temperatures exist, it is helpful to change the temperature of the components. By raising the temperature, mixing is faster and easier, and the tendency to whip air into the compound during mixing is reduced. Care must be taken not to raise the temperature too much, because it can shorten the amount of working time available to use or place the mixed components. The manufacturer's mixing instructions should be checked to obtain the working time of the epoxy-hardener mixture at different temperatures. If the ambient temperature is too high, both the epoxy resin and the hardener can be cooled to increase the working time.

29. After mixing, each batch must be discharged within a limited time, because the chemical reaction of the hardening process starts as soon as the ingredients are mixed.

#### PART IV: GROUTING TECHNIQUES AND EQUIPMENT

30. There are three general techniques used for injecting epoxy resin-hardener mixtures into cracks:

- a. Hand caulking gun.
- b. Pressure pot.
- c. Dispensing machines.

The hand caulking gun and the pressure-pot technique require mixing of the epoxy resin and hardener components manually, whereas the epoxy dispenser does the mixing in the system immediately prior to injection.

31. The equipment and procedures discussed in this report are designed for grouting at ambient or low pressures. Crack injecting to stop flowing water under pressure is not covered in this report and requires high-pressure equipment.

##### Hand Caulking Gun

32. There are several types of caulking guns and caulking gun cartridges which have been used for pressure grouting (see Appendix C for a list of suppliers), although the standard 1/12-gal caulking tube with a 3-in. nozzle and standard caulking gun can be used for most low-pressure situations. The components of a hand-operated caulking gun are shown in Figure 5. The

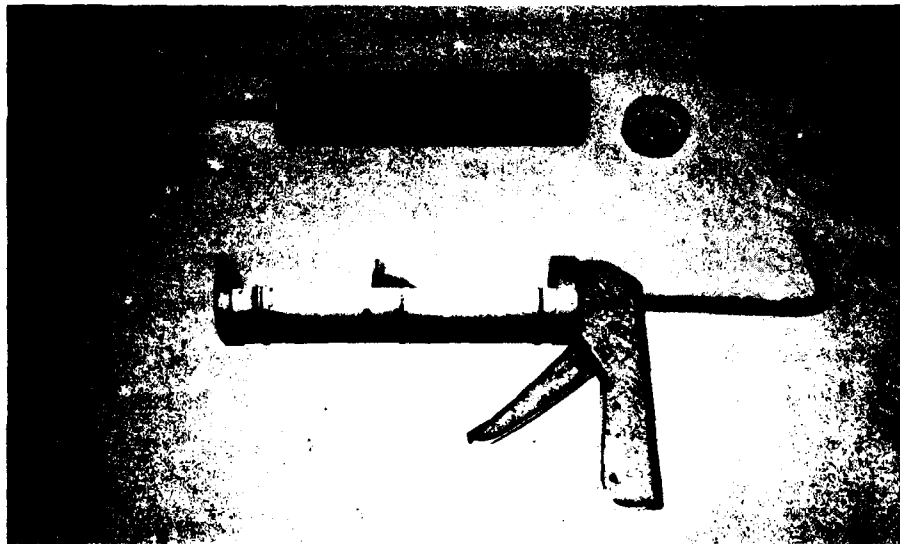


Figure 5. Hand caulking gun used for grouting

epoxy resin-hardener mixture is poured into the caulking tube, then the cap is placed into the tube. The cartridge is then inserted into the gun, and the tip end of the plastic nozzle must be cut off to allow the entrapped air to escape and permit the mixture to flow from the tube during grouting. Some tubes might have a thin sheet of aluminum foil sealing the nozzle from the tube. This seal can be easily punctured with any sharp object (e.g., a 16-penny nail). The nozzle is pointed up and the trigger is pumped to force the air out of the tube.

33. The hand caulking gun is now ready for use and it should be used before the pot life of the epoxy has been exceeded. In the event that the epoxy starts to cure (indicated by undue warming of the steel cover) the cartridge should be removed and discarded, along with any epoxy left in it. A new cartridge filled with freshly mixed epoxy resin can then be inserted and injection can continue.

34. Pneumatic-powered hand caulking guns are available, if the grouter wishes to facilitate or expedite the grouting operation. An example is shown in Figure 6. The operation is identical to that with a hand-powered gun except that air is used to force the plunger instead of force applied with the hand trigger.

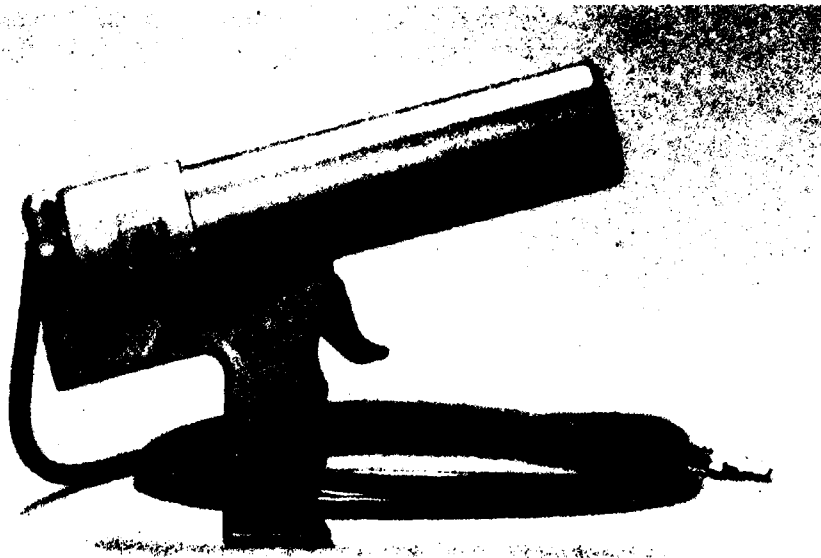


Figure 6. Pneumatic-powered hand caulking gun

## Pressure Pot

35. Cracks can be grouted by injection of the epoxy resin using a pressure pot. The pressure pot apparatus is very similar to equipment that is used for spraying paint. The equipment used by the US Army Construction Engineering Research Laboratory (CERL) is shown in Figure 7 (US Army Construction Engineering Research Laboratory 1971) and Figure 8 (American Concrete Institute 1980). Usually a 2-gal pressure tank or pot is used as the reservoir for the freshly mixed epoxy resin. The pot should have the capacity of operating at 100 psi using either compressed air or an inert gas. The pressure source should have the capability of maintaining a pressure that is greater than the pressure that is in the reservoir. Also, the system should be operated with a pressure regulator to ensure precise control of the injecting pressure. CERL (1971) states,

The line (a) comes from an oil-, moisture-, and dirt-free pressure source. This is connected through the entry valve (b) to the pressure regulator (c) which in turn allows controlled air flow into the tank. The outlet or location where the epoxy compound leaves the tank is at (d). The 3/8-in. outlet is reduced to a 1/4-in. shutoff needle valve (e). To the valve is joined a 1/4-in. nipple and 1/4-in. cross (f). The cross provides for three pressure injection lines. Each line is preceded by a 1/8-in. exit valve (g), the outlet of the 1/4-in. cross having been reduced to 1/8-in. The epoxy injection line is 1/8-in. inside diameter Imperial Eastman Hylo-Seal 'F' Tubing No. C902-1/8 with a 1,000-psi rupture rating.

The tank must also be equipped with an emergency pressure release valve (h) which must be adjusted to release at 5 to 10 psi less than the maximum allowable pressure of the equipment. The tank is also equipped with a manual pressure release valve (i).

36. The pressure pot should be placed close to the injection ports. The injection hose should not exceed 10 ft in length to minimize pressure losses in the system.

37. Figure 8 shows the inside of the pressure tank along with the epoxy compound container. The desired amount of the mixed epoxy resin compound is placed in a 1/2-gal plastic container which is then placed in the pressure tank. A 300-psi flexible rubber feed line, of sufficient length to reach the bottom of the plastic container, is attached to the inside of the outlet port on the lid of the pressure tank. The lid is placed on the tank ensuring that

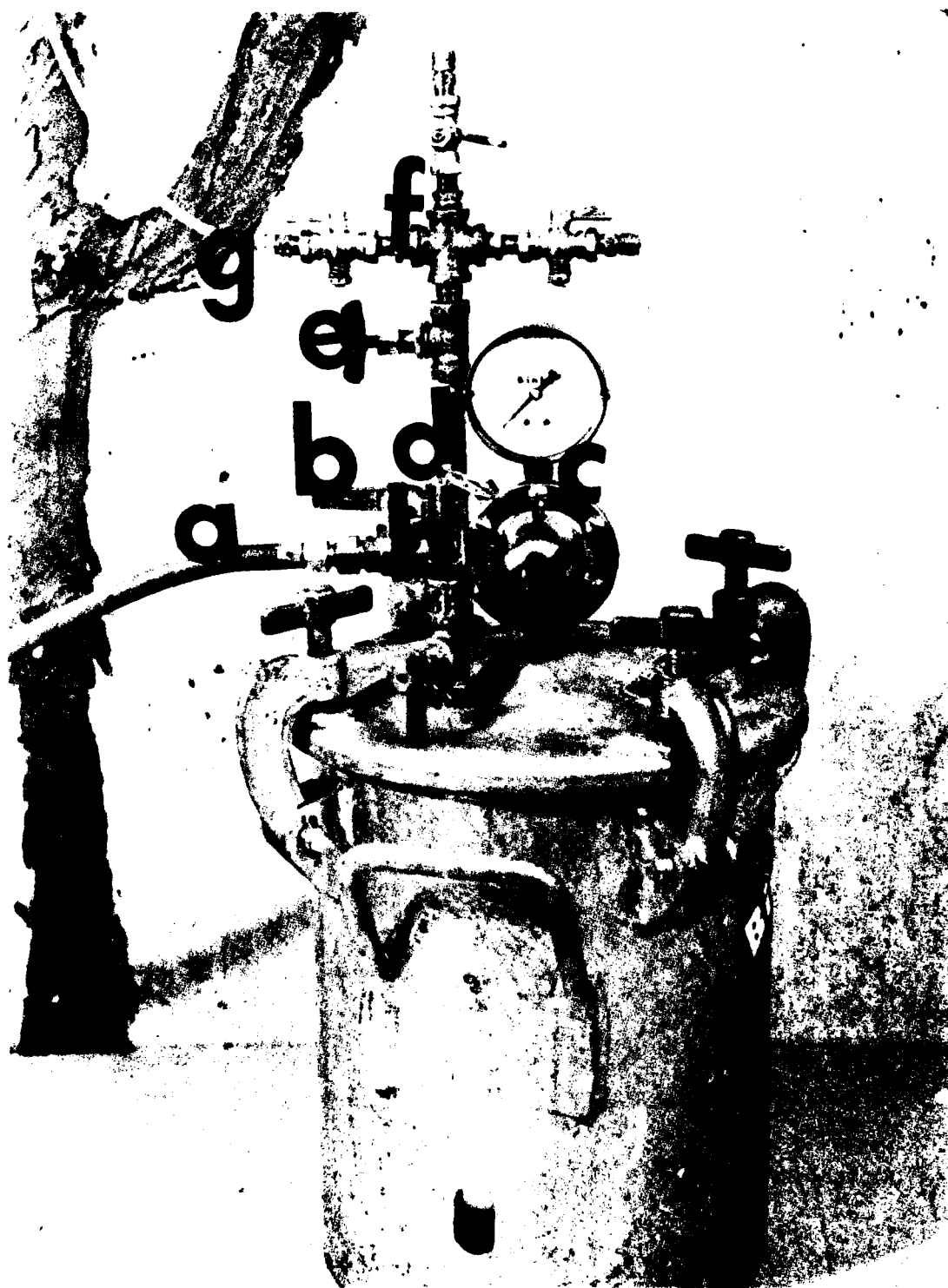


Figure 7. Pressure pot and related grouting apparatus (CERL 1971)

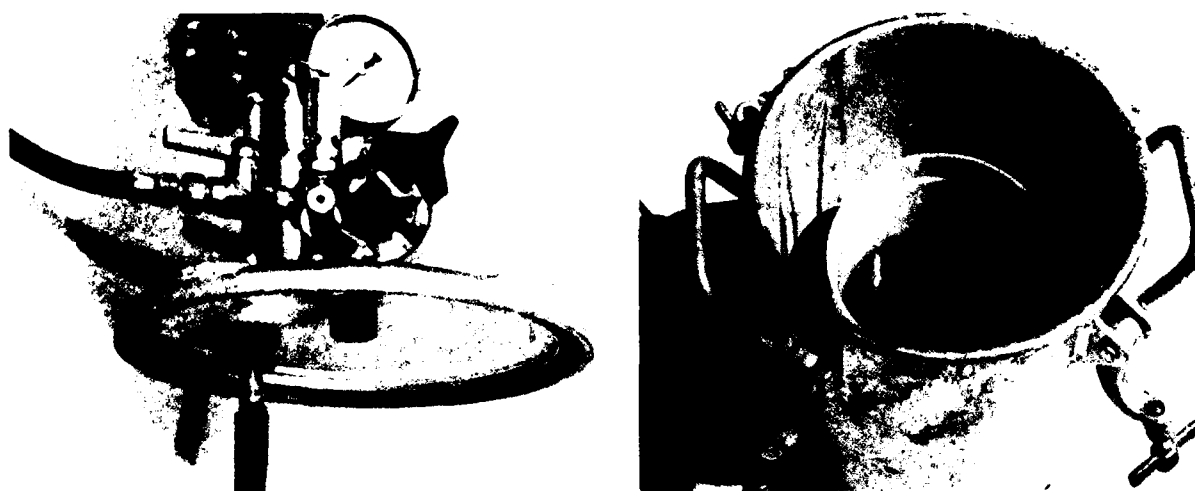


Figure 8. Open pressure pot  
(Taken from Concrete International September 1980)

the feed line is inside of the plastic container. A pressure pot ready for use is shown in Figure 8.

#### Dispensing Machines

38. The fastest and easiest method of grouting cracks is with an epoxy dispenser. The epoxy is mixed in the mixing chamber as it is needed; therefore there is no concern about pot life and the danger of the epoxy setting up in the pot and in the lines.

39. Several types of equipment have been developed for the purpose of pumping the proper proportions of epoxy resin and hardening agent to a mixing nozzle or mixing head at or near the injection port. This equipment is all proprietary in nature and therefore it is not possible to give any details concerning its makeup.

40. An important aspect of such equipment is that it is impossible to know for certain what proportions of the mixture are being injected into a crack. Therefore, the use of this equipment should only be allowed when two control devices are provided. This is discussed in Part VII.

41. If the components are color coded, then a visual examination of the epoxy compound, as it leaves the injection nozzle, will indicate whether proper mixing of the components is being obtained. For example, the resin component might be black and the hardener component might be white, so that the resulting mixture becomes a uniform gray. A sample of the epoxy compound

can be injected into a small container. Improper mixing would be denoted by streakiness, or by nonuniform coloring, or both. In the event that either of the above criterion is not met, all pressure grouting operations should cease until proper remedial action has been taken.

42. An example of an epoxy dispenser is shown in Figure 9. For this system the epoxy resin is placed in the canister labeled 'A' and the hardening agent placed in the canister labeled 'B'. Each component is pumped by the proportioning pump (C) through the feed lines (D) to the mixing chamber and exit nozzle (E). A remote control switch (F) is attached to the feed lines to enable the operator to control the pump while injecting the grout into the

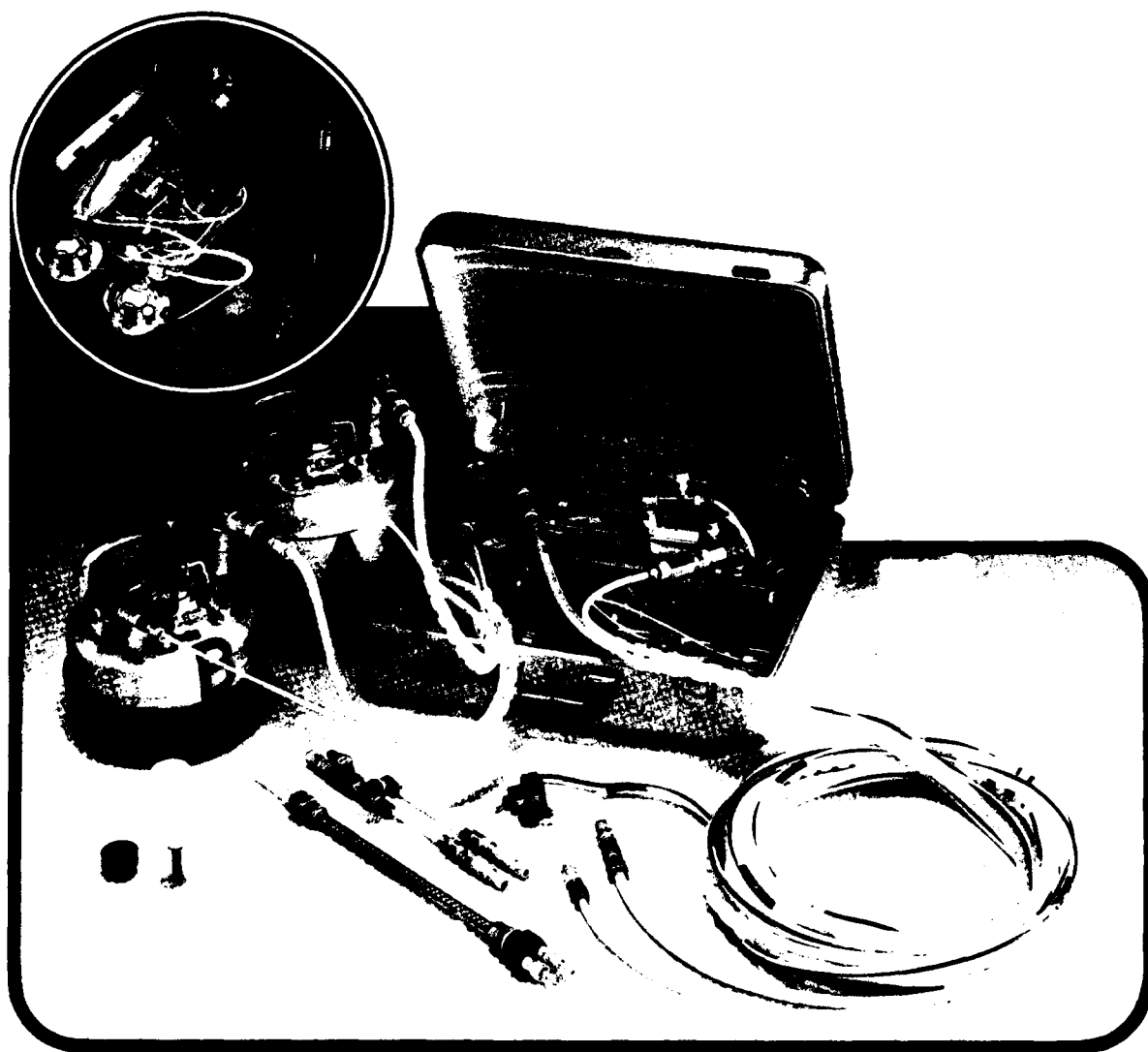


Figure 9. Example of a high-pressure epoxy dispenser



ports. An air purge adapter (G) can expedite cleaning the equipment after the grouting is completed.

43. The complete system must be solvent flushed after the injection process is completed or for any period longer than 1 week. (Components A and B may be stored in their respective reservoirs up to 1 week.) The mixing chamber must be thoroughly flushed if the grouting is to be stopped for a period longer than the pot life of the material.

44. The system should be flushed out with compressed air to remove any solvent left in the system. Solvent should not be mixed with epoxy to be grouted. The solvent will evaporate after the epoxy cures, leaving voids and weak spots in the cured material. General specifications for epoxy dispensers are included in Appendix D and a list of epoxy dispenser manufacturers is contained in Appendix E.

## PART V: INJECTION

### Trial Run

45. It is recommended that a trial run be accomplished before the actual grouting of the damaged structure begins. This will be highly beneficial to inexperienced persons and will serve as a refresher course to those who have not grouted cracks for a long time. If there are no concrete cracks to practice on, a simulated crack may be made by clamping two pieces of wood together. Very small aggregate (about 1/16 in.) is placed between the pieces of wood to make a void. The ports are installed and the edges are sealed to confine the grout. This is a good simulation and many mistakes can be corrected before the actual grouting is started.

### Quantity of Grout Required

46. An estimate of the amount of epoxy grout which will be required for any given job can be calculated using the following formula (developed by CERL 1971):

$$Q = 0.7DLW$$

where

Q = quantity of epoxy grout required, pt

D = desired depth of penetration, in.

L = lineal feet of crack to be grouted

W = crack width, in.

0.7 = constant taking into account waste and other unpredictable factors

To expedite the operation, the epoxy grout components should be obtained in pint containers for hand caulking guns and pressure pots, and in gallon containers for epoxy dispensers.

## Quantity of Grout to be Mixed

### Hand gun

47. The amount of epoxy to be mixed for hand caulking gun grouting will be determined by the need to be ready when the gun is empty. This will be determined by the injection flow rate; however, if this has not been established, a good starting volume is 1 pt of resin and 1 pt of hardener.

### Pressure pot

48. CERL 1971 states "the amount of epoxy grout to be mixed and placed in the pressure pot at any one time is determined by the width of the cracks being grouted as shown in the following table:"

<u>Crack Width</u>	<u>Quantity of Epoxy Grout</u>
0.003 to 0.010	1 pt
0.010 to 0.020	2 pt
0.020 to 0.125	3 pt

49. The above quantities are based upon: pot life and flow rate. The flow rate is determined by the amount of epoxy grout which can be injected into a crack per unit of time - the smaller the crack, the lower the flow rate.

50. As can be determined from above, the widest cracks will receive the most grout in a given length of time. Therefore, within pot life limitations, large volumes can be mixed when grouting into wide cracks. The above table should only serve as a guide. After the grouting has commenced, it may be found desirable to make adjustments to the quantity mixed and placed in the pressure pot. For example, a wide crack may accept 3 pt of grout in such a short time that more time may be spent in recharging the pressure pot than in actual grouting. Therefore, an increase in the amount of grout initially placed in the pot would be justified. However, the increase in quantity will shorten the pot life.

### Epoxy dispensers

51. Since the epoxy grout is mixed prior to injection, the amount to be mixed (or amount placed into the machine to be mixed) is determined by the volume of the voids in the cracks. Since the epoxy grout components can be stored in the machine for up to 1 week, the components should be added in increments of gallons depending upon the volume needed within the week. If

the components have not been mixed, the materials in the machines can be used any time within the next 7 days. Do not leave mixed epoxy grout in the mixing chamber longer than the pot life of the material.

### Grouting Procedures

52. The injection process begins by pumping the epoxy resin mixture into the ports at the lowest elevation for vertical or inclined cracks and the port at one of the ends of a horizontal or near-horizontal crack. The pumping of the mixture into the first port should continue until the epoxy adhesive starts to come out of the adjacent port. Then the first port is plugged and the pumping operation into the next adjacent port begins. After grouting into a port has been completed, a good method of plugging the filled port is by the use of tapered wooden dowels. Anything that can be forced into the port to stop the flow of the grout may be used (e.g., pencils, corks, rubber tubing). Care must be taken to inject the epoxy adhesive at such a rate that the injection pressure does not exceed that pressure which the surface seal can tolerate or which might damage the structure. If port-to-port travel of epoxy adhesive is not indicated, grouting shall be stopped immediately and an investigation should be conducted to determine where the epoxy adhesive is being pumped.

#### Hand caulking gun

53. After the epoxy and hardener are mixed properly, the mixture is poured into the cartridge. The end cap is placed into the cartridge; then the sealed cartridge is placed into the gun. The nozzle is pointed up and away from the operator; then, about 1/8 to 1/4 in. of the tip of the plastic nozzle is cut off. The aluminum seal in the cartridge is broken, if necessary. A little time is allowed for most of the entrapped air bubbles to rise to the surface of the mixture, and then displace the remaining air at the top of the cartridge with epoxy resin. The hand caulking gun is now ready for grouting. The grouting operation should be started shortly to prevent the epoxy resin from gelling in the cartridge. The end of the plastic nozzle is inserted into a port opening. The gun is held firmly in place and pressure is applied to the epoxy by squeezing the trigger (Figure 10). Flow of the epoxy can be monitored by watching for the movement of air bubbles in the plastic nozzle. The sequence of injecting into the portals is the same as that described in

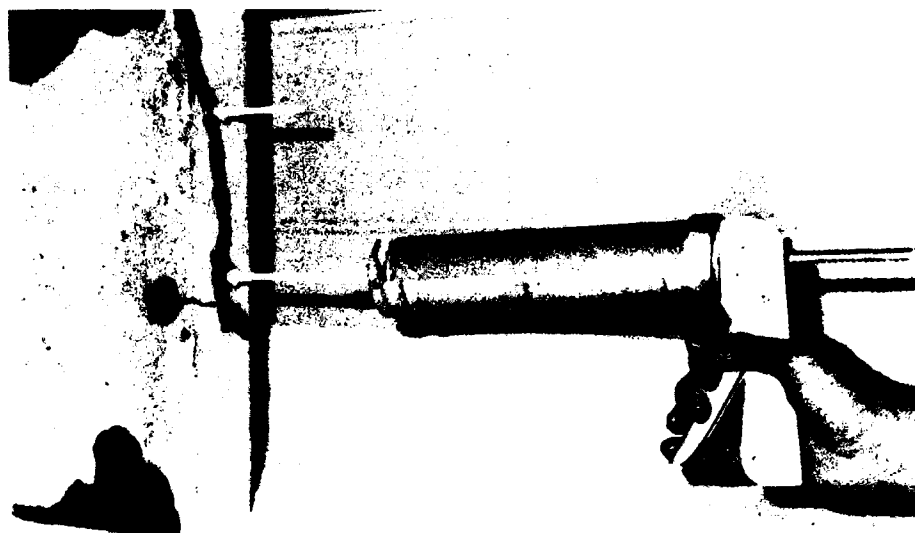


Figure 10. Grouting with a hand caulking gun

the processing paragraph. If the epoxy-resin mixture in the cartridge starts to generate heat, the pot life is about to be reached. At that point, the epoxy is beginning to set and it should not be used because it has become thicker and will not penetrate into the smaller voids. An increase in the temperature of the tube is a good indication that setting is beginning. If the epoxy-resin in the gun starts to set, the epoxy should be discarded, along with the cartridge. Another cartridge is filled with freshly mixed epoxy resin and grouting is continued before the epoxy resin in the crack begins to set. As long as the epoxy does not start to stiffen in the cartridge, it may be used continuously.

#### Pressure pot injection

54. The freshly mixed epoxy grout is poured into the 1/2-gal plastic container, then the plastic container is placed into the pressure pot. The lid is secured on the pressure pot, the exit valves are closed, and the pot is pressurized. The injection flow lines are inserted into an entry portal. Each line should go to the bottom port of a vertical crack or to an end port of a horizontal crack first. In order to insure continuity of the injected material within the crack, it is recommended that each continuous crack be grouted using only one injection line (CERL 1971).

55. After the lines have been placed, the exit valve of the pressure pot is opened to start the flow of the epoxy into the cracks. Flow of the

epoxy can be monitored by watching the movement of small air bubbles in the line. Generally, a few small bubbles can be found. If none are present, bubbles can be introduced by closing the exit valve for the desired line, removing and then replacing the line. When the exit valve is opened, an air bubble will appear. The line is left in place until the epoxy starts to flow out of the adjacent portal. The injection line is moved to the next portal, and the portal which was just used is plugged. However, if intermediate portals have been placed, as discussed in Part II, the injection line is not moved until the epoxy grout reaches the portal spaced at the desired depth of penetration. As the epoxy appears at each intermediate portal, the portal is plugged. In the event that flow ceases due to blockage before the grout reaches the desired portal, the injection line should be moved to the next portal which has not been plugged.

56. The portals can be plugged by inserting any suitable material into the opening as discussed in the hand caulking gun injection section. The grouting process should be a continuous operation, and interruptions must be kept to a minimum. To minimize the time required to replenish the epoxy in the pot, a new batch should be mixed approximately 5 min prior to the pot life of the material in the pressure pot. As soon as the new batch of epoxy grout has been mixed, the grouting operation is stopped by shutting off the pressure entry valves and the epoxy exit valves (Figure 7). The tank then is depressurized by opening a pressure release valve. An attempt to depressurize the pot should never be made by removing the lid. When the gage pressure reaches zero, the lid is opened and the plastic container is removed and discarded. The new container of freshly mixed epoxy is placed in the tank. The lid is replaced and secured, and the tank is pressurized. Before resuming the grouting operation, the old epoxy should be bled from the lines. This is done by removing all lines from the portals, holding the ends of the lines over a waste container, and opening the epoxy exit valves. The lines are bled until the old epoxy has been completely removed. This is indicated by the presence of large air bubbles which are automatically entrapped between the old and fresh epoxy during the changeover. Once the fresh epoxy has reached the end of the lines, the exit valves are closed, the ends of the lines are replaced into the portals, and the exit valves are opened to resume grouting.

57. Should the supply of epoxy grout in the pressure vessel be depleted before the pot life is reached, fresh epoxy should be mixed as rapidly as

possible. The same procedure as outlined above is used for recharging the pressure pot.

58. Any delay in the pressure grouting operation (e.g., lunch break, quitting time, etc.) over 15 min in duration demands that the pressure pot be cleaned and all lines thoroughly cleared of epoxy compound. This is accomplished by pumping a full container of toluene, methylethyl ketone (MEK), or other recommended solvent through all lines into a waste container. This process is then repeated with a one-half-full container of solvent. Air is then blown through the lines to remove any residual solvent. This process will leave the equipment ready for reuse.

#### Dispensing machine

59. To use the epoxy dispenser, the epoxy resin and hardener are poured into their proper canisters. The desired ratio to be pumped is set. About 2 oz of epoxy are pumped to flush out anything that might be trapped in the lines or mixing chamber. To ensure correct mix proportioning, the ratio check device is connected and testing is performed as described in the manufacturer's instruction manual. The pumping ability of the equipment is tested by connecting the pressure device and performing testing as instructed in the manual. If the testing proves the equipment is functioning properly, grouting may commence. The same procedures are followed as described with the pressure pot injection.

60. The epoxy dispenser allows continuous mixing and injecting until one or both of the canisters are empty. When more materials are needed, fresh materials are added to the proper canisters and grouting is continued. The canister, flow lines, or mixing chamber assembly do not need to be cleaned up when more ingredients are added. The epoxy and hardener can be kept in the machine up to 1 week, provided the mixing chamber assembly is cleaned properly (as described in the equipment section). The mixed epoxy resin and hardener should not be kept in the mixing chamber and exit nozzle longer than the pot life of the material. The material will set up and the mixing chamber assembly can no longer be used. After the grouting operation has started, the procedure described in Part IV, the equipment section, is to be followed for checking the pressure-maintaining ability of the equipment.

## Grouting Cracks Underwater

61. The same procedure used in grouting cracks not submerged should be followed in grouting cracks underwater; however, a denser material will have to be used. The epoxy resin that is used for cracks not submerged can be modified or a resin specially formulated for underwater crack injection may be purchased. If the epoxy grout used for nonsubmerged cracks is not dense enough to be placed underwater, it will try to float. Filler must be added to obtain a higher density than water so that the epoxy grout will displace water from the crack. If a filler is added, it should be added to the epoxy resin component and thoroughly incorporated with the resin before the epoxy resin and hardener are mixed together. The manufacturer can give instructions on how to modify a grout for underwater application. ASTM C 882-78, "Bond Strength of Epoxy-Resin Systems Used with Concrete," can be used to determine the bond strength of an underwater injection grout (American Society for Testing and Materials 1984a). Two half cylinders are placed together with 1/16-in. spacers between them to create a void for the grout to fill. The crack between the half cylinders is sealed after entry ports have been installed. After the sealant has hardened, the specimen is placed underwater and grouted with epoxy resin. Then the ports are plugged after the void is filled. The specimen is kept submerged to allow for underwater curing of the epoxy resin grout. After curing, the specimen is tested in compression in accordance with ASTM D 695-80 (American Society for Testing and Materials 1984b). A specimen being injected underwater is shown in Figure 11.



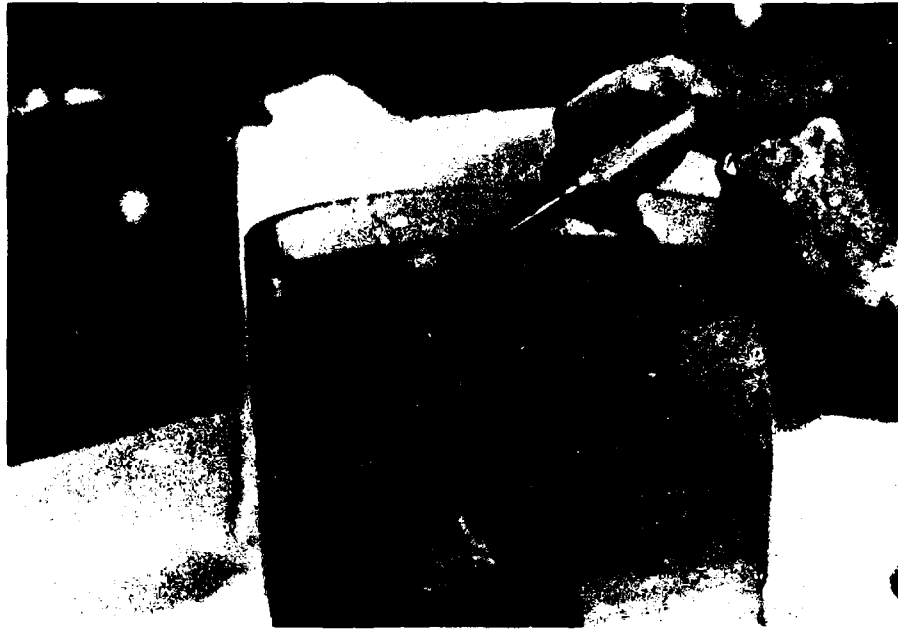


Figure 11. Injecting a specimen underwater

## PART VI: CLEANUP

### Spillage

62. Epoxy or hardener spillage should be scooped up or wiped up. The remainder then can be wiped up with rags wetted with a solvent (e.g., xylene, toluene, methylethyl ketone, or acetone). In some situations the spillage can be reacted with its counterpart and left in place if this will not present a problem later.

63. All empty epoxy component containers should be immediately placed in leakproof waste containers and discarded.

### Cleaning the Hand Grouting Gun

64. Cartridges used in the hand grouting gun should be discarded any time that grouting stops. If necessary, the hand grouting gun should be cleaned with solvent and rags.

### Cleaning the Pressure Pot

65. To ensure that the epoxy resin mixture does not set up in the port or in the line, methylethyl ketone, toluene, or another recommended solvent should be flushed through the pressure pot and the line. The flushing should be done at the end of each day's work, at the completion of the job, or any time it appears that the epoxy resin might set up in the equipment. After a job has been completed and the equipment is not to be used for some time, it is advisable to completely disassemble and clean the equipment prior to storage.

### Cleaning the Dispensing Machine

66. The manufacturer's instruction literature will describe correct methods to properly clean the dispensing machine.

## PART VII: QUALITY CONTROL (EPOXY)

67. Epoxy resins are no different from any other construction material. A good result depends entirely on:

- a. Selection of the right material for the given conditions.
- b. Careful surface preparation.
- c. Proper handling, mixing, and application.
- d. Satisfactory curing.

Failure to observe any of these four points will lead to inferior quality.

### Field Control - Compression Tests

68. Just as concrete cylinders are made at a jobsite to check the quality of the concrete delivered and placed, specimens of the epoxy resin grout should be taken for use in control tests. These tests should become an integral part of any job since it is the only nondestructive way of assuring that a quality epoxy compound has cured within the grouted structure.

69. To facilitate the mechanics of curing of epoxy resin compounds, an analogy can be made with portland cement concrete:

	<u>Epoxy Resin Compound</u>	<u>Portland Cement Concrete</u>
Compressive strength testing time	2-3 days	28 days
Surface hardness/ indication of strength	Durometer	Windsor probe
Temperature dependent for setting	Highly	Slightly
Consistency	Gel time and/ temp. rise	Slump or unit weight test
Working time	Gel time*	Initial set

---

\* Discrepancies in the gel times are good indications that the cross-linking process of resin and hardener is not functioning properly.

70. In the field, one compressive strength test specimen should be taken for every 2 hr of grouting performed. This is done by filling a

specimen mold with the epoxy grout from the exit nozzle of the injection device. The specimen is to be taken from the actual grout being injected into the crack. After filling the mold, the epoxy should be allowed to take an initial set before removing from the jobsite. The specimen will be cast, cured, and tested in compression according to ASTM D 695-80 (American Society for Testing and Materials 1984b). The values shall be greater than 75 percent of ultimate value.

71. Since surface hardness is directly proportional to the compressive strength of the specimen, a surface hardness test can be performed on three of every four cylinders. The testing will be performed after the specimens have cured for 48 hr at 73° F. Temperature and hardness will be measured in accordance with ASTM D 2240-81 (American Society for Testing and Materials 1984c) using a D durometer. The durometer reading shall be within  $\pm 5$  D durometer units of a control's durometer reading. A control is a 48-hr cured specimen which meets the compressive strength requirement. If the specimen does not meet the  $\pm 5$  unit, then the specimen shall be tested in compression to ensure the quality of the grout. The compressive strength values obtained should not be less than the minimum values listed in the specifications for the material.

72. If epoxy-dispensing equipment is used for the grouting, the pressure check test and the mixing ratio test shall be performed as described in the equipment section of this report.

#### Flow of Grouting Material

73. As has been indicated in earlier sections of this guide, flow of the epoxy grout is essential. Inspection must continually be made of the transparent injection lines or the plastic hand grouting gun nozzle, watching for the movement of small air bubbles. Movement of the air bubbles assures that flow is taking place. A buildup of pressure in the epoxy dispenser equipment can detect when the flow of grout has stopped.

74. Although the equipment has pressure switches to shut off the pumps if one of the components is not flowing, a visual inspection can reveal major mixing and proportioning problems. Any change in color or streaking in the mixed ingredients should indicate that the equipment may be malfunctioning.

## Core Drilling

75. Coring of the bonded cracks may be performed for making an evaluation of the grout penetration within the cracked structure if there is any question about the integrity of the structure.

## Pump

76. To ensure that the proper volumes of each component are being delivered while subjected to back pressure, the volumes being pumped should be checked periodically. Testing should be performed before the grouting has started and continued on a weekly basis until the operation is completed. To test the proportioning, the mixing head of the injection equipment shall be disconnected and the two adhesive components shall be pumped simultaneously through the ratio check device. The ratio check device shall consist of two independent valved nozzles capable of controlling back pressure by opening or closing the valve. A pressure gage capable of sensing the back pressure behind each valve should be used. The discharged pressure should be adjusted to 180 psi for both adhesive components, then both adhesive components should be simultaneously pumped into separate calibrated containers (e.g., graduated cylinders). The amounts pumped simultaneously during the same period into the calibrated containers should be compared to determine if the volume ratio is correct. If the amounts delivered vary more than the 2-percent allowance, adjustments will be made to correct the improper proportioning.

77. To ensure that the equipment is not malfunctioning and that the proportion ratio is not changing due to leakage or seepage back through the pump, testing of the equipment's pressure-maintaining ability is performed. This testing should be performed before the grouting has started for that day or shift, and repeated daily. Testing sometimes should be performed at random times during the operation. To test the pressure-maintaining ability of the equipment, the mixing head should be attached to the pressure check device. The pressure check device should consist of two independent valved nozzles capable of controlling flow rate and pressure by opening or closing the valve. A pressure gage capable of sensing the pressure buildup behind each valve should be provided. The valves on the pressure check device should be

190 psi. At that point, the pumps are stopped and the gage pressure must not drop below 170 psi within 3 min. If the pressure drops more than 20 psi in 3 min, grouting must be stopped until the problem is corrected. Proper installation of a repair kit as instructed in the service manual should correct the pressure problem.

## PART VIII: SAFETY AND HANDLING PRECAUTIONS

78. As with any other material, epoxies must be handled in a safe and conscientious manner. Generally, the epoxy resins are safer materials than the catalyst. There are two typical health problems which may be encountered when using epoxy materials: skin irritations and skin sensitization (American Concrete Institute 1980). The best prevention is to avoid contact of these materials with the skin. Safety glasses or goggles are strongly recommended when handling and injecting epoxies. The use of disposable clothing (including gloves) made with an impermeable material (e.g., plastic or rubber) makes working with these materials safer and easier. Any permeable material (e.g., cotton) should be removed immediately and discarded if contaminated with epoxy or hardener. If skin comes in contact with these materials, the best thing to do is to wash the exposed skin with soap and water. Solvents should not be used because they dilute the epoxy and expose a larger skin area. Solvents can also irritate the skin.

79. If the material comes in contact with the eyes, immediately flush the material out with large amounts of water and seek medical attention. When working with solvents, all the standard safety precautions should be followed.

## PART IX: CONCLUSIONS AND RECOMMENDATIONS

80. Concrete which has nonworking cracks can be repaired successfully by epoxy injection if the proper techniques and materials are used. Some things to consider when repairing by epoxy injection are: depth and width of the crack, temperature of the concrete, and the presence of moisture. Conditions will dictate the kind of epoxy which should be used.

81. As with any other repair method, there are limitations to epoxy injection; good judgment should be exercised. The intent of this report is to provide basic principles of epoxy injecting and to supply the reader with a knowledge of the available equipment, materials, and techniques.

82. For small jobs, the hand caulking gun is a convenient method of repairing cracks. For large jobs, the pressure pot or epoxy dispensing machine would be the preferred method because of the volume of epoxy resin that can be injected and the shorter amount of time required to do the injecting. If injection equipment is to be purchased, it is the author's opinion that the dispensing machine would be the better option because of its faster injection capability and ease of operation.



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- a. "Bond Strength of Epoxy Resin Systems Used with Concrete," Designation: C 882-78, Section 4.
  - b. "Compressive Properties of Rigid Plastics," Designation: D 695-80, Section 8.
  - c. "Rubber Property - Durometer Hardness," Designation: D 2240-81, Section 8.
  - d. "Specification for Epoxy-Resin-Base Bonding Systems for Concrete," Designation: C 881-78, Section 4.
  - e. "Standard Definitions of Terms Relating to Plastics," Designation: D 883-83, Section 8.
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- US Army Construction Engineering Research Laboratory. 1971 (Jul). "Guide for Pressure Grouting Cracked Concrete and Masonry Structure with Epoxy Resin," Technical Report M-9, Champaign, Ill.

## APPENDIX A: DESIRABLE QUALITIES OF AN INJECTION RESIN

Gel time, pot life: 25 min minimum at 73° F	ASTM D 2471-66T
Compressive strength, 28 days: 8,000-psi minimum	ASTM D 695-80
Tensile strength: 4,000-psi minimum	ASTM D 695-80
Bond strength, 14 days: 1,500-psi minimum	ASTM C 882-78
Specific gravity: Greater than 1	
Viscosity: 500-cps maximum without filler	ASTM D 2393-68
Modulus of elasticity: 340,000 minimum	
Final cure (75 percent ultimate strength): 2 days at 73° F	
Color: One component is white; the other is black; mixture of components is gray.	
Weight per epoxide: 160-278	ASTM D 1652-67
Container size: 1-pt or 1-gal units	
Solvents or diluents: Must be 100 percent reactive, no nonreactive materials.	
Safety data: Must supply safety information with materials.	

APPENDIX B: SOME MANUFACTURERS OF EPOXY RESIN

Adhesive Engineering Company  
1411 Industrial Road  
San Carlos, California 94070

(415) 592-7900

Dural International Corporation  
95 Brook Avenue  
Deer Park, New York 11729

(516) 586-1655

General Polymers Corporation  
Post Office Box 12168  
Cincinnati, Ohio 45212

(513) 631-0649

I. W. Industries  
6119 Westview  
Post Office Box 19452  
Houston, Texas 77024

(713) 681-0345

Parmigile Epoxies  
101 Commercial Street  
Plainview, New York 11803

(516) 349-1100

Protex Industries, Inc.  
1331 West Evans Avenue  
Denver, Colorado 80223

(303) 935-3566

Sika Corporation  
Post Office Box 297  
Lyndhurst, New Jersey 07071

(201) 933-8800

APPENDIX C: SUPPLIERS FOR HAND CAULKING TUBES

Suppliers for Standard Hand Caulking Guns

Kardon Industries, Incorporated  
West Route 36, Post Office Box 930  
St. Paris, Ohio 43072

(513) 663-4142

Semco Products Research and Chemical Corporation  
18881 South Hoover Street  
Los Angeles, California

SONOCO-Products  
761 Space Drive  
Alpha, Ohio 45301

(513) 429-0040

Suppliers for Air-Powered Hand Caulking Guns

Albion Engineering Company  
2080 A Wheatsheak Lane  
Philadelphia, Pennsylvania 19124

(215) JE-5-3476

Semco Division Products and Chemical Corporation  
5454 San Fernando Road  
Glendale, California 91209

(213) 247-7140

Vital Products Manufacturing Company  
14501 Industrial Avenue S.  
Maple Heights, Ohio 44137

(216) 663-2800

#### APPENDIX D: SPECIFICATIONS FOR EPOXY DISPENSERS

Dispensing pressure: 0 to 200 psi

Accuracy: The equipment shall have the ability to dispense volumes within 2 percent of desired amount up to a pressure of 180 psi; designed to connect properly to any port diameter from 1/8 to 1/2 in.

Material line: Dual; one for each port; 15 ft in length; must be able to withstand pressure of 200 psi.

Fittings: All are to be quick-disconnect types, coded for error-free hookup.

Controls: Pressure control at mixing head.

Place of mixing: Shall occur in line in exit nozzle apparatus.

Pump: Positive displacement piston type with the capability to dispose any ratio ranging from 1:1 to 4:1.

Pumping capacity: 4 gal/hr minimum.

Inertness: Mixing head, component tank, line, and nozzle exit shall be solvent resistant, and shall not be subject to corrosion under normal conditions.

Automatic shutoff: The equipment shall be equipped with sensors on both the component A and B flow systems that will automatically stop the machine when only one component is being pumped to the mixing head.

Accessories: Repair kit, to be able to perform minor repairs; service manual, to instruct how to perform minor repairs; extra mixing head; extra hose, enough for a total length of 45 ft; pressure check device, to enable the operator to check the pressure-maintaining ability of the equipment; ratio check device, to enable the operator to check for the proper ratio while subjected to back pressure; containers to perform ratio check test, three each.

Safety: The reservoir cannot be opened under pressure.

Mixing head performance: The manufacturer shall provide test results that his product will sufficiently mix the two components.

APPENDIX E: EPOXY DISPENSER MANUFACTURERS

E-Poxy Industries, Incorporated  
14 West Shore Street  
Ravena, New York 12143

(518) 756-6193

Lily Corporation  
33 West 480 Fabyan Parkway  
Suite 103  
West Chicago, Illinois 60185

(312) 232-4422

Otto Controls  
Otto Engineering, Incorporated  
2 East Main Street  
Carpentersville, Illinois 60110

(312) 428-7171

Protex Industries, Incorporated  
1331 West Evans Avenue  
Denver, Colorado 80223

(303) 935-3566

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EPOXY-RESIN GROUTING OF CRACKS IN CONCRETE (U) ARMY  
ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS  
STRUCTURES LAB D L BEAN DEC 85 WES/MP/SL-85-18

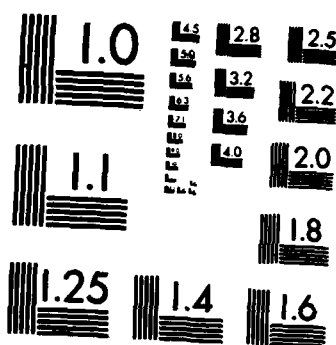
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MICROCOPY RESOLUTION TEST CHART  
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DEPARTMENT OF THE ARMY  
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS  
P.O. BOX 631  
VICKSBURG, MISSISSIPPI 39180

REPLY TO  
ATTENTION OF

WESSN

11 July 1986

Errata Sheet

No. 1

EPOXY-RESIN GROUTING OF CRACKS  
IN CONCRETE

Miscellaneous Paper SL-85-18

December 1985

1. Page 4. Change the conversion factor for pounds (force) per square inch to read:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
pounds (force) per square inch	0.006894757	megapascals

2. Page A1. Change line 8 to read:

Modulus of elasticity: 340,000 psi minimum

3. Page A1. Change line 12 to read:

Epoxy content of epoxy resin: 120-278 gram equivalents  
of epoxy groups per 100 grams  
of resin

END

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DTIC